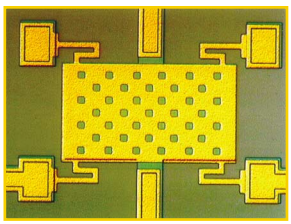
Research at Intel
Micro Electro-Mechanical Systems (MEMS)



Optical micrograph of a MEMS varactor. The varactor consists of a metal membrane suspended by four tethers at the corners. There are three electrodes below the membrane, the center one for capacitance and the two side ones for electrostatic actuation.

Micro Electro-Mechanical Systems (MEMS) is an emerging technology used to create micro-miniature mechanical devices out of silicon. These devices can then be integrated into microchips and used in a variety of applications, from sensors in automobile airbags (a common current use for the technology) to proactive computing applications that could leverage MEMS-based sensors and actuators embedded in the environment. Our project focuses on the use of MEMS in the wireless arena, to improve the performance of RF (radio frequency) systems.

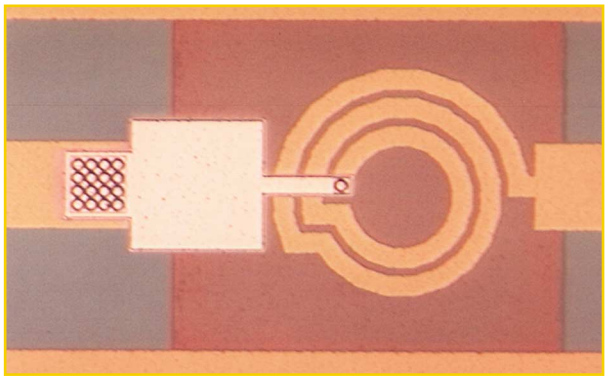
In carrying out our research, we benefit from close ties to other MEMS researchers in industry, academia, and within our company. Intel is a founding member of the MEMS Industry Group (MIG), the trade association representing the U.S. MEMS industry. Our membership in MIG enables us to exchange ideas and share knowledge with other companies that are pursuing MEMS research. We also collaborate with university researchers, primarily at UC Berkeley and the University of Michigan, through our memberships in the Berkeley Sensor and Actuator Center (BSAC) and the Wireless Integrated Microsystems (WINS) consortium. Internally, we interface closely with other MEMS researchers, including those who are conducting research into biomedical applications of MEMS.

Research Agenda

Within the MEMS project, a variety of subprojects are being carried out. The following are highlights of research in progress.

RF MEMS Building Blocks

In the wireless arena, passive components such as filters, switches and tuning elements used in cell phones, cable modems, and LANs take up a lot of real estate on printed circuit boards. MEMS technology could enable us to fabricate a variety of these high-value passive components on a silicon substrate and integrate them onto a MEMS chip. We are exploring these RF MEMS building blocks, which could lead to lower cost, smaller footprint and extended battery life as well as improvements in reliability.



Optical micrograph of a high Q-factor inductor on a dielectric membrane. The silicon material underneath the membrane was etched away to eliminate substrate induced losses and parasitic effects.

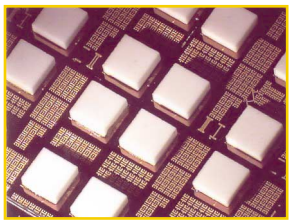
Process Technology Development

MEMS is based on fabrication technologies similar to CMOS. Our research focuses on two methods of fabricating MEMS: surface micromachining and bulk micromachining. Our main goals are to find ways of implementing these methods, to the extent possible, using standard CMOS processing, and to apply CMOS VLSI development methodology to develop robust MEMS process technologies that can be manufactured in large volumes. We also are exploring ways to apply a VLSI yield improvement methodology to MEMS technology.

MEMS process development in Fab 8 utilizes existing capabilities for CMOS processes, supplemented by an isolated pilot line with gold processing tools dedicated for MEMS.

Packaging

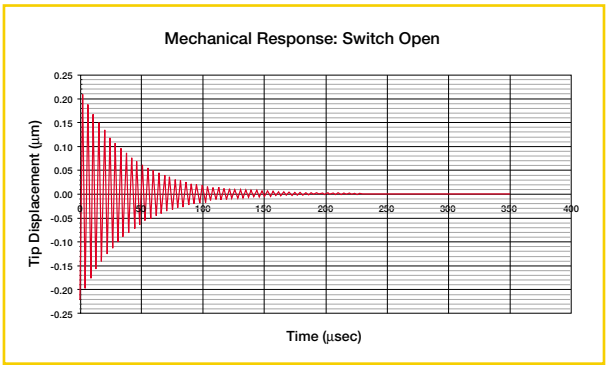
Since MEMS technology is silicon-based, the ideal scenario would be to integrate the micromachined and CMOS devices monolithically onto one piece of silicon. One challenge in doing so is a basic incompatibility of the environmental requirements for MEMS and CMOS. MEMS devices typically require hermetic or vacuum environments to operate reliably, whereas non-hermetic plastic packaging is the norm for CMOS chips. Integrating them monolithically mandates hermetic packaging. Our research focuses on integrating CMOS and MEMS devices in a hermetic packaging environment. We are exploring wafer bonding technology as a way to achieve this.



RF MEMS components packaged at the wafer level using ceramic caps. The ceramic caps were bonded to the wafer using pick-place technology after the MEMS devices were fabricated and released. Glass frit was used as the bonding agent for hermeticity. For high volume production, wafer level packaging is necessary because MEMS devices must be released at wafer level and protected by packages before singulation.

MEMS Tests and Characterization

In a typical MEMS chip, the actual moving elements typically only move a few tenths to a few hundredths of a nanometer. This presents an enormous challenge in the characterization of these devices to ensure that they operate as simulated. Accurate characterization is required to calibrate simulation tools. To address this challenge, we are exploring new testing and characterization methodologies for MEMS. Our research focuses on the simultaneous measurement of both RF and mechanical operation. For the latter, we have applied optical interferometric techniques to precisely measure displacements with a precision of better than 0.1 nm. In addition, a key requirement for improving design and process is feedback on why and how real devices fail. Therefore, we are also developing novel techniques to perform failure analysis of MEMS devices.



The vibration of a switch upon opening, as monitored using an instrument based on the laser Doppler effect.

People

Project Leader : Valluri Rao, Ph.D.

Valluri Rao is an Intel Fellow and Director of Analytical and Microsystems Technologies at Intel's Technology and Manufacturing Group. Dr. Rao is currently directing Intel's Microsystems and MEMS research and development activities. He is also responsible for directing the development of advanced analytical tools and methods for microprocessor performance characterization, silicon debug and yield enhancement.

Dr. Rao joined Intel in 1983 and has worked on the development and corporate-wide deployment of analytical capability and infrastructure for Intel products, beginning with the 386 processor.

Dr. Rao received B.A., M.A. and Ph.D. degrees in electrical engineering from Jesus College, University of Cambridge. He was a post-doctoral research fellow at Cambridge from 1979 to 1983. He holds 19 patents, with seven patents pending, in the areas of analytical tools, high-speed measurements and optical interconnects. He has published over 20 papers and has received three Intel Achievement Awards, all for developing and deploying key analytical capability throughout the company.

Research Team

The MEMS Research Team is composed of a core team working collaboratively with researchers in Fab 8 in Israel. Core team members are Qing Ma and Daniel Wong, Managers; Tsung-Kuan Allen Chou, John Heck, Joseph Hayden III, Dong Shim, Quan Tran, and Li-Peng Wang

MEMS Research team:
From left to right: (standing) Yair Weissler (Fab 8), Eyal Ginsburg (Fab 8), Israel Yankovich (Fab 8), Allen Chou, Daniel Wong, Li-Peng Wang, Valluri (Bob) Rao, Alex Telalyevsky (Fab 8), Eyal Bar-Sadeh (Fab 8), Dong Shim, Qing Ma. (seated) Hanan Bar (Fab 8), Joe Hayden, John Heck, Eyal Ginsburg (Fab 8), Quan Tran (Fab 8).

About Intel Research

In a future world of proactive computing, billions of tiny, powerful, connected devices throughout the environment will anticipate our needs and take appropriate action on our behalf. With the formation of Intel Research in 1999, Intel began funding research into the emerging and disruptive technologies required to translate this vision into reality.

Intel has initiated several projects in support of proactive computing. A number of strategic research projects are being carried out internally, within Intel's research and development labs. These projects cover a broad range of disciplines, including MEMS, precision biology, ad hoc networks, extreme networked systems, ubiquitous computing, novel storage, live databases, statistical models, computational nanovision, robotics, machine learning, supply chain visualization, distraction-free systems, proactive healthcare, and ethnography.

Complementary research into proactive computing is being conducted externally through the Intel Research Network of labs, an innovative partnering between industry and academia. The labs, located near major universities, are wholly owned and funded by Intel but operate using a uniquely open and collaborative model. Much of the research they generate will be published and shared widely. Currently there are four labs in the network, in Berkeley, Pittsburgh, Seattle and Cambridge, England.

The Intel Research Network of labs builds upon Intel's strong history of research and development, both within the company and through more than 250 funded university projects throughout the world. Intel also supports research institutions through a variety of programs, including Intel forums, visiting faculty collaboration, and joint Intel-university research projects. Intel is an active participant in Sematech, the Semiconductor Research Corporation, and other industry consortia.

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